3.1.6   Ground Water

3.1.6.1   Hydrostratigraphy

Rush et al. (1982), Weir, Maxfield, and Hart (1983), and Weir, Maxfield, and Zimmerman (1983) grouped the aquifers in the northern part of the Paradox Basin into lower and upper hydrologic systems. The upper ground water system consists of unconsolidated and bedrock formations above the impermeable salt beds of the Paradox Formation. Confining salt beds of the Paradox Formation underlie most of the site and locally contribute to high levels of salinity in the overlying unconsolidated basin-fill aquifer. The lower ground water system includes all the stratigraphic units below the Paradox Formation. Site-related ground water contamination occurs in the unconsolidated basin-fill aquifer in the upper hydrologic system. Water-bearing characteristics of major stratigraphic units from the Paradox Formation and above are presented in Figure 3–6.

3.1.6.2   Ground Water Occurrence

Ground water occurs in the bedrock formations and unconsolidated Quaternary material deposited on the floor of Moab and Spanish Valleys. The Navajo Sandstone, Kayenta Formation, and Wingate Sandstone of the Glen Canyon Group contain the principal bedrock aquifer in the region and locally are present only upgradient at the northern boundary of the site. The Navajo Sandstone of the Glen Canyon aquifer ranges in thickness from 300 to 700 ft (Doelling et al. 2002) and is the shallowest and most permeable formation in the Glen Canyon Group. Wells located 7 to 8 miles southeast of the site produce in excess of 1,000 gpm of high-quality water from the Navajo Sandstone for the city of Moab water supply.

Estimated transmissivity for the Navajo Sandstone ranges from near 0 to 700 ft^2/day, and estimated hydraulic conductivity ranges from 0.4 to 1 ft/day (Blanchard 1990). Specific capacities of two water-supply wells at the entrance to Arches National Park, completed in the Navajo Sandstone, were 1.7 and 14.5 gpm per foot (Blanchard 1990). Average saturated thickness of the gravelly sand that constitutes the unconsolidated basin-fill aquifer is approximately 70 ft (Sumsion 1971). This basin fill material may be as much as 450 to 500 ft thick in Moab Valley.

Most of the freshwater in the basin-fill aquifer enters the site from Moab Wash and along geologic contacts between the alluvium and the Glen Canyon Group bedrock present at the north boundary of the site. The bedrock in this area is highly fractured and faulted from incipient collapse of the Moab anticline caused by dissolution of the underlying Paradox Formation salt core of the anticline.

Ground water elevation of the freshwater in the basin fill alluvium is shown in Figure 3–7. West of the Colorado River, these shallow water-table contours are based on average water elevations measured in 2001 and 2002. Contours east of the Colorado River in the Matheson Wetlands Preserve are based on March 2003 water elevation measurements and indicate ground water flow toward the river. The elevation contours indicate that freshwater entering the site at the northern boundary flows south toward the river over the top of a deeper natural brine zone.
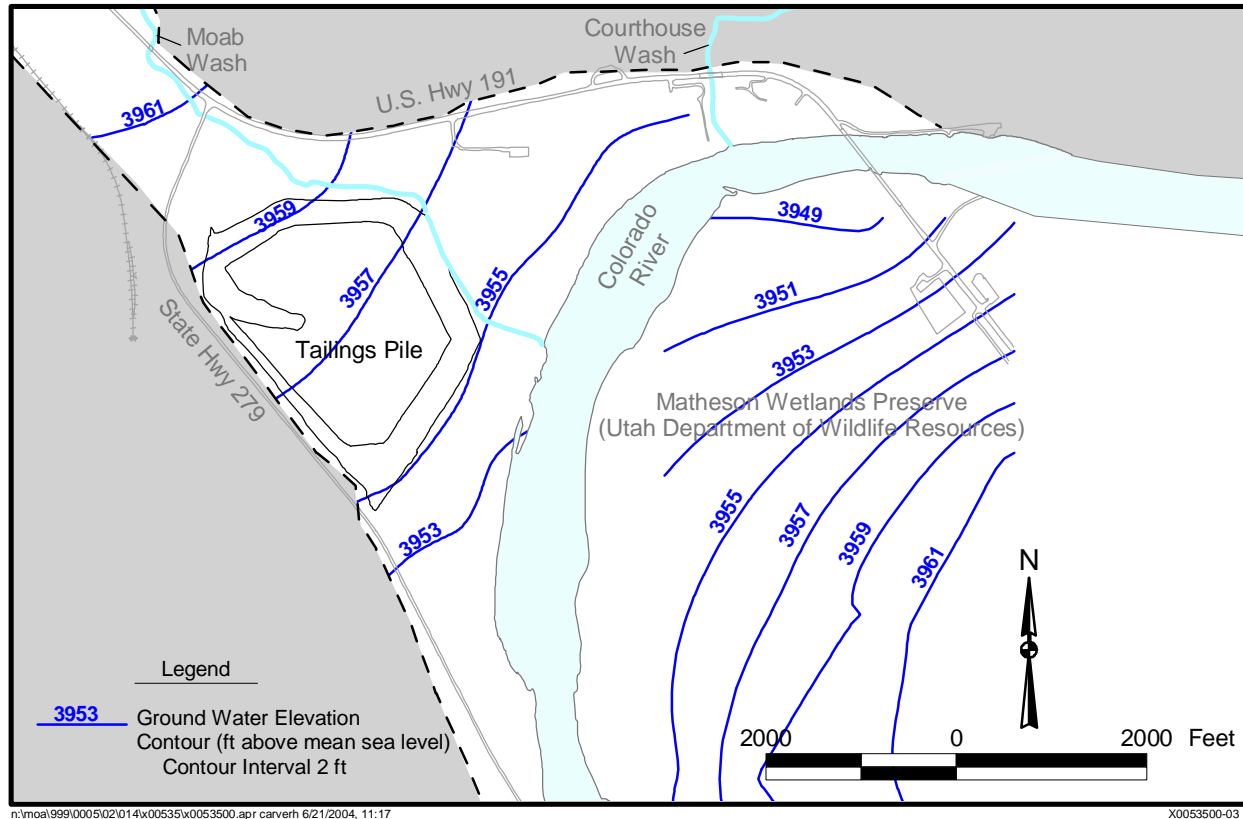
Figure 3–7. Ground Water Elevation Contours on the Upper Freshwater Surface

The deeper brine water results mostly from dissolution of the underlying salt beds of the Paradox Formation present beneath most of the site. Figure 3–8 presents a conceptual model of the subsurface hydrogeology along a representative streamline showing the interface between the deeper saltwater system and the overlying freshwater system. The saltwater interface is defined at the 35,000-mg/L TDS boundary. The transition from the saltwater to the freshwater system occurs over a short vertical distance and is, therefore, referred to as being "sharp." The vertical position of the interface is in equilibrium because the buoyant force exerted by the brine is balanced by the weight of the overlying freshwater. In natural systems, little, if any, freshwater penetrates saltwater at the interface. The freshwater can be thought of as a liquid that "floats" upon a buoyant saltwater liquid. At the Moab site, the interface extends across the site in a wedge shape, in which the deepest part of the interface is near the northwest boundary, and the shallowest depth is near the river. The position of the interface near the river is in dynamic equilibrium and probably shifts laterally and vertically in response to evapotranspiration by the tamarisk plant communities and the stage of the Colorado River. The interface may also shift vertically upward as a result of pumping from the shallow freshwater (e.g., during a pump-and-treat remediation) and cause the saltwater to rise to a higher elevation and intrude the freshwater. Saltwater intrusion would result in degradation of the overlying freshwater, which could adversely affect the tamarisk plant communities that are providing some beneficial phytoremediation at the site.
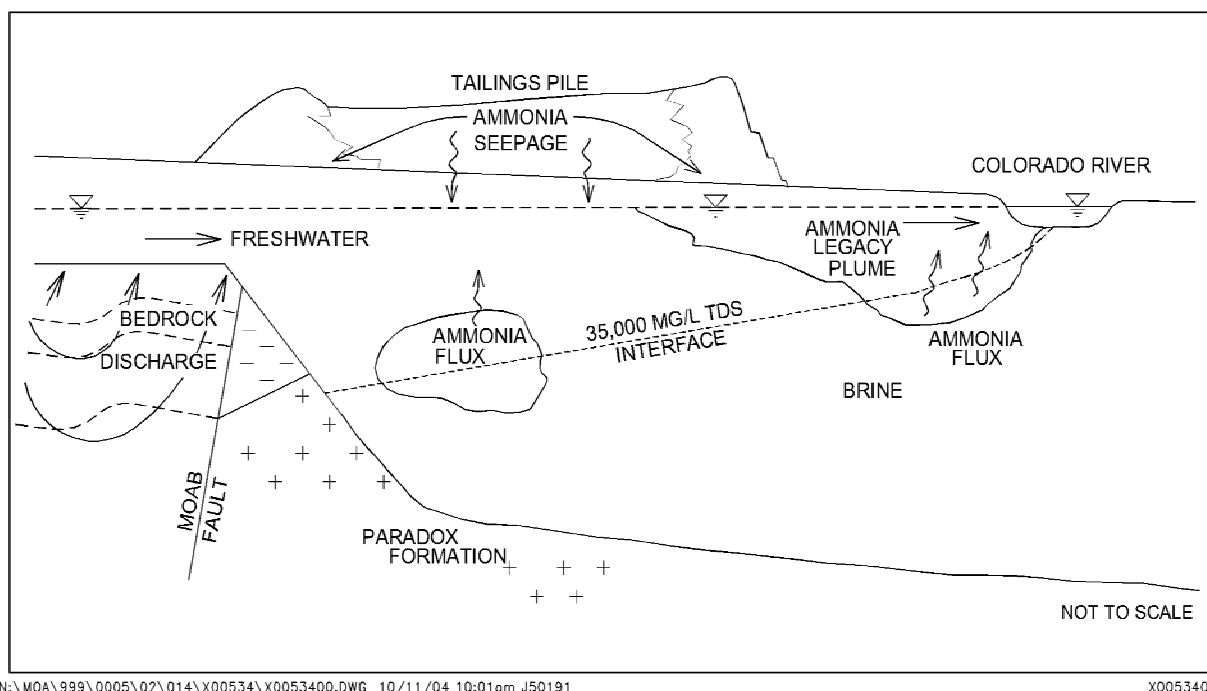
N:\MOA\999\0005\02\014\X00534\X0053400.DWG 10/11/04 10:01am J50191   X0053400

Figure 3–8. Conceptual Model, Saltwater/Freshwater Interface

Rising saltwater may also bring higher ammonia and salt concentrations to the surface and cause added contamination flux to the river. Low pumping rates and proper extraction well construction and pump location may prevent saltwater intrusion. Additional information on the hydrogeology of the site is presented in the SOWP (DOE 2003).

Additional recharge to the site occurs through precipitation. The Paradox Formation is believed to be an impermeable boundary (bedrock aquitard) and does not contribute to the site water budget. An estimate of the annual steady-state water budget for each hydrologic component of the system is presented in Table 3–6. Short-term transient effects such as the small positive contribution to bank storage by recharge from the Colorado River during periods of high flow are not included. The estimates are represented with a large range of individual values, and the ranges of the total inflow and total outflow do not overlap, reflecting the uncertainty of the values and suggesting that the true water budget might lie between the two ranges. The SOWP (DOE 2003) provides additional discussion of the ground water hydrology and water budget of the site.

Table 3–6. Estimated Annual Water Budget for the Moab Site

Flow Component	Inflow (gpm)	Outflow (gpm)
Areal Precipitation	16–65	N/A
Moab Wash	0.5–33	N/A
Glen Canyon Group	28–280	N/A
Tailings Pile	20	N/A
Evapotranspiration	N/A	200–500
Colorado River	N/A	300–600
Total	**65–400**	**500–1,100 (rounded)**

N/A = not applicable.

3.1.6.3   Ground Water Quality

The basin-fill aquifer underlying the site is divided into three hydrochemical facies: (1) an upper fresh to moderately saline facies (fresh Quaternary alluvium [Qal]) that has concentrations of TDS up to 10,000 mg/L, (2) an intermediate facies of very saline water (saline Qal), having TDS concentrations between 10,000 and 35,000 mg/L, and (3) a lower briny facies (brine Qal) that has TDS concentrations greater than 35,000 mg/L. All three facies existed beneath the site prior to milling activities. The SOWP (DOE 2003) provides additional discussion of ground water geochemistry and water quality at the site.

A cross-sectional view of contoured TDS concentrations beginning at Moab Wash and extending southeast to the Colorado River is shown in Figure 3–9. The interface between the upper freshwater with the deeper saline water is shown by the 35,000-mg/L contour line. Sixty percent of the alluvial aquifer is contained in the lower briny facies. More than 80 percent of the basin-fill aquifer contains TDS concentrations that are greater than 10,000 mg/L. The upper hydrochemical facies contains limited freshwater with less than 3,000 mg/L TDS that could provide potable water (Figure 3–9). The volume of ground water containing 3,000 mg/L or less TDS represents less than 3 percent of the total volume in the basin-fill aquifer beneath the site. All the freshwater with TDS concentrations less than 3,000 mg/L that could provide potable water occurs upgradient of the tailings pile near Moab Wash. Though some of the TDS in the freshwater system is from recent contamination, the percentage of the aquifer that would return to TDS concentrations of less than 3,000 after remediation would be minimal.

The freshwater quickly becomes mixed with more saline water in the basin-fill aquifer as it enters the site from Moab Wash and flows toward the Colorado River. Salinity naturally increases with depth and distance from the freshwater source contribution from Moab Wash. Mixing of the two background water types (fresh upgradient water with the deeper depth saline water) influences the background water quality at the site. The result is a background water quality in the basin-fill aquifer that is highly variable both vertically and horizontally across the site.

Background conditions in the upper fresh Qal facies are characterized by low concentrations of uranium and other trace metals that are all below the EPA standards in 40 CFR 192 (Table 3–7). TDS concentrations range from 677 to 7,820 mg/L, which classifies the water quality as fresh to slightly saline. Background alkalinity as calcium carbonate ranges from 137 to 189 mg/L. There is no EPA standard for ammonia in 40 CFR 192. Ammonia–N concentrations are less than 1 mg/L. Sulfate concentrations range from 180 to 1,140 mg/L. Calcium concentrations range from 47 to 294 mg/L. Magnesium concentrations range from 31 to 188 mg/L. On average, the pH value of the upper fresh Qal facies is near neutral (7.7), and the redox condition is slightly oxidizing (oxidation-reduction potential is 186 millivolts [mV]).

Table 3–7. Standards for Inorganic Constituents in Ground Water at UMTRCA Project Sites

Constituent	Standards[a]		Background[a]	
	EPA (40 CFR 192)[b]	SDWA[c]	Fresh Qal Facies Range	Brine Qal Facies Range
Arsenic	0.05	0.01	0.00018-0.0015	0.00015-0.11
Barium	1.0	2.0	0.0222-0.033	0.031-0.121
Cadmium	0.01	0.005	<0.0001-<0.0017	<0.0001-0.014
Chromium	0.05	0.1	<0.0005-<0.011	<0.003-<0.01
Lead	0.05	N/A	<0.0001-<0.0055	0.00054-0.184
Mercury	0.002	0.002	<0.0001-<0.0002	<0.0002-<0.0002
Molybdenum	0.1	N/A	<0.0018-0.01	<0.004-<0.009
Nitrate (as N)	10[d]	10[d]	1.22-15.9	<0.02-0.075
Selenium	0.01	0.05	0.0091-0.0266	<0.0001-0.009
Silver	0.05	N/A	<0.0001-<0.0055	<0.0001-<0.004
Radium (combined radium-226 and radium-228)	5 pCi/L	5 pCi/L	N/A	N/A
Radium-226	N/A	N/A	0.07–0.16 pCi/L	<0.29–9.26 pCi/L
Radium-228	N/A	N/A	<0.5–1 pCi/L	2.6–6.09 pCi/L
Uranium (combined uranium-234 and uranium-238)	0.044[e]	0.03	0.0042–0.0259	0.0007–0.0269
Gross alpha-particle activity (excluding radon and uranium)	15 pCi/L	15 pCi/L	<6.73-<73.92 pCi/L	<356.33-<473.08 pCi/L

[a]Concentrations reported in milligrams per liter (mg/L) unless noted otherwise; pCi/L = picocuries per liter.
[b]Maximum concentration limits, 40 CFR 192, Table 1, Subpart A.
[c]Maximum contaminant levels, Safe Drinking Water Act, 40 CFR 141.23 and 141.62.
[d]Equivalent to 44 mg/L nitrate as NO_3.
[e]Equivalent to 30 pCi/L, assuming secular equilibrium of uranium-234 and uranium-238.
 N/A = not applicable

Background conditions in the lower brine Qal facies are characterized by a poor water quality resulting from the dissolution of gypsum and salt beds in the underlying bedrock formations. The water is a sodium-chloride type with TDS concentrations up to 97,000 mg/L, which classifies the water quality as briny. Maximum detected concentrations of arsenic (0.11 mg/L), cadmium (0.014 mg/L), and lead (0.184 mg/L) are all slightly higher than EPA standards in 40 CFR 192. Maximum concentrations of uranium (0.027 mg/L) are less than the EPA standard. Ammonia background concentrations range from 0.03 to 3.0 mg/L. Secondary Safe Drinking Water Act standards are exceeded for sulfate (250 mg/L), chloride (250 mg/L), manganese (0.05 mg/L), and iron (0.3 mg/L), demonstrating the poor quality of the brine Qal background ground water. Secondary standards are unenforceable.

Site-related constituents have contaminated the basin-fill aquifer beneath the tailings pile and beneath the former millsite. Ammonia, nitrate, sulfate, molybdenum, uranium, gross alpha, and gross beta are the site-related constituents most prevalent in the basin-fill aquifer. The relatively low distribution ratios (R_ds) measured for uranium and ammonia concentrations explain the higher prevalence of these site-related constituents, which are conserved in the ground water and are more easily dispersed from the source area. Similarly, molybdenum and nitrate are geochemically conservative and tend to be highly mobile in ground water under almost all conditions.

Concentrations of magnesium, cobalt, manganese, and strontium exceed the upper limit of the range in natural background for the fresh Qal facies in more than 50 percent of the samples but

do not exceed the upper limit of natural background for the brine Qal facies in any of the samples. Similarly, cadmium and nickel concentrations exceed the upper limit of natural background for the fresh Qal facies in more than 50 percent of the samples but exceed the upper limit in natural background for the brine Qal facies in only 3 percent or less of the samples. This low frequency reflects the relatively high concentrations that occur naturally in the Paradox Formation brine.

Other site-related constituents are present at concentrations above the upper limit of natural background; however, concentrations exceed background less frequently. For example, arsenic concentrations exceed the upper limit in approximately 35 percent of the samples when compared to the fresh Qal background but in only 3 percent of the samples when compared to the brine Qal background. Selenium concentrations exceed the upper limit in approximately 29 percent of the samples when compared to the fresh Qal background and in 54 percent of the samples when compared to the brine Qal background. Vanadium concentrations exceed the upper limit in approximately 19 percent of the samples when compared to the fresh Qal background and in 10 percent of the samples when compared to the brine Qal background. Antimony, barium, chromium, lead, mercury, silver, and zinc concentrations exceed the upper limit of natural background for either the fresh or brine Qal facies in only 10 percent or less of the samples.

Ground water concentration limits for arsenic, barium, cadmium, chromium, lead, mercury, molybdenum, nitrate, selenium, silver, uranium (combined U-234 and U-238), gross alpha (excluding radon and uranium), and radium (combined radium-226 and radium-228) are regulated by EPA standards (see Table 3–7). Of these constituents, the maximum concentrations detected for arsenic, cadmium, uranium, radium, gross alpha, nitrate, selenium, and molybdenum exceed EPA standards. The remaining regulated constituents (barium, chromium, lead, mercury, and silver) are all present at relatively low concentrations below EPA standards.

The areal distribution of uranium concentrations greater than 0.044 mg/L, interpolated and contoured on the upper surface of the ground water, is presented in Figure 3–10. The highest uranium concentrations are in the shallow ground water in the former millsite area. Cross-sectional views of the uranium plume and additional isoconcentration maps of uranium as a function of depth are provided in the SOWP (DOE 2003). SMI (2001) suggested that the high uranium concentrations beneath the millsite are caused by waste leaking from the former wood chip disposal areas. Although the uranium plume is in an area where wood chip disposal was likely to have occurred, lithologic logs of borings installed in this area of the site do not indicate that they penetrated through the wood chip pits. Another possible source of the high uranium concentrations is the uranium ore stockpiles; however, samples collected from monitor wells nearest the largest known ore stockpiles have lower uranium concentrations. Whether the source of the high uranium concentrations in ground water samples is the wood chip pits, the ore stockpiles, or some other millsite-related release, it seems that some of the ground water contamination originates in the millsite area, independently of the tailings pile.

Although ammonia has no EPA standard in 40 CFR 192, it occurs at concentrations significantly greater than natural background, is one of the most prevalent contaminants in the ground water, and is the constituent of greatest ecological concern that is discharging to the Colorado River in backwater areas adjacent to the site. The areal distribution of ammonia concentrations greater than 50 mg/L, interpolated and contoured on the upper surface of the ground water, is presented in Figure 3–11. The highest concentrations in the shallow ground water, greater than 500 mg/L,

appear near the downgradient edge of the pile and extend to and discharge to the Colorado River. The highest ammonia concentrations in surface water samples are detected in samples collected closest to the riverbank adjacent to the tailings pile and immediately downstream of Moab Wash. A comparison of ground water data with surface water data shows that, with few exceptions, concentrations of site-related constituents are much lower in the surface water than in the ground water. Ammonia concentrations in the river are approximately 2 orders of magnitude lower than in the ground water. Although available data are not adequate to establish an accurate dilution factor, these data do suggest that at least order-of-magnitude decreases in constituent concentrations can be expected as ground water discharges to the river. Isolated pools or very shallow areas may be exceptions to this; however, those locations are temporary and are unlikely to represent important aquatic habitat.

Relatively high ammonia concentrations in ground water also occur at depth beneath the tailings pile (Figure 3–12). During milling operations, the tailings pond contained fluids with TDS concentrations ranging from 50,000 to 150,000 mg/L. Because these salinities exceed 35,000 mg/L, they had sufficient density to migrate vertically downward through the freshwater system and into the brine. This downward migration of the tailings pond fluids into the saltwater system is believed to have created a reservoir of ammonia that now resides below the saltwater interface. This ammonia plume below the interface probably came to rest at an elevation where it was buoyed by brine having a similar density. Under present conditions, the ammonia plume beneath the saltwater interface represents a potential long-term source of ammonia to the freshwater system. The conceptual model presented in Figure 3–8 illustrates the ammonia source at the saltwater interface (basal flux), the legacy plume, and seepage of ammonia from tailings pore fluids.

3.1.6.4   Ground Water Use

Historical records indicate that two water supply wells were present at the site before milling operations began in 1956 (DOE 2003). Both wells were located near the northwest area of the tailings pile. Records indicate that the first well, designated as well C, was installed to a depth of 67 ft by the U.S. Department of the Interior Grazing Service in 1940 and provided approximately 20 gpm from the basin-fill aquifer, presumably used for livestock watering. The second well, designated as well B, was installed to a depth of 114 ft by the U.S. Atomic Energy Commission in 1954 just prior to mill construction. The zone of completion for well B is unknown. This well produced approximately 11 gpm through a perforated casing and was presumably used to supply process water for the mill. In both cases, the quality of the water is unknown, and the wells have subsequently been decommissioned. No other water wells are known to have existed at the site prior to milling.

The Navajo Sandstone of the Glen Canyon aquifer, which ranges in thickness from 300 to 700 ft (Doelling et al. 2002), is the shallowest and most permeable formation in the Glen Canyon Group. Consequently, it is the primary target for most bedrock wells drilled in the area (Eisinger and Lowe 1999). The city of Moab derives most of its drinking water from a well field that is completed in the Glen Canyon aquifer near the northeast canyon wall of Spanish Valley (Blanchard 1990). Two water-supply wells located near the entrance to Arches National Park are completed in the Navajo Sandstone.

Numerous springs flow from the Navajo Sandstone. Flux from these springs is limited to less than 10 gpm but is sufficient to provide water for a few cattle (Doelling et al. 2002). Other consolidated formations in the Spanish Valley, such as the Entrada Sandstone, are capable of transmitting and yielding small quantities of water but are not important as a water resource (Sumsion 1971).

Unconsolidated basin-fill deposits make up a secondary aquifer used mostly for irrigation and some domestic water supply in Spanish Valley (Steiger and Susong 1997). More than 200 wells completed in the unconsolidated material in the Moab-Spanish Valley area (Sumsion 1971) range in depth from 30 to 300 ft (Eisinger and Lowe 1999). Water in the unconsolidated aquifer is generally of poorer quality than that of the Glen Canyon and Entrada aquifers. Near the Colorado River, TDS and trace metals concentrations in the basin-fill aquifer increase as a result of dissolution of the underlying Paradox Formation salt beds (Cooper and Severn 1994).

3.1.7   Surface Water

3.1.7.1   Surface Water Resources

The Moab site is located within the Southeast Colorado Watershed Management Unit as designated by UDEQ's Division of Water Quality (UDEQ 2000). This watershed unit includes the Colorado River in the vicinity of the Moab site and all its tributaries and other water bodies between the Colorado River and the Colorado/Utah state line.

The principal surface water resource in the area, the Colorado River, lies 500 to 700 ft from the easternmost extent of the tailings pile, which is located on alluvial material deposited by the river. It flows south along the east edge of the site, and flows in deeply incised bedrock canyons cut by the river at the northeast and southwest borders of Moab Valley. The Colorado River flows south out of Moab Valley through The Portal, 1,000-ft sandstone cliffs flanking the entrance to the river canyon. The river drains one of the most arid sections of the North American continent. The rugged mountains, broad basins, and high plateaus in the Upper Colorado Basin (above Lees Ferry, Arizona) have been deeply entrenched and dissected (Price and Arnow 1974).

Courthouse Wash empties into the Colorado River 0.5 mile upstream from the tailings pile, and Moab Wash crosses the site along the north and east sides of the tailings pile. The channel of Moab Wash was rerouted east of the mill during operations to mitigate flooding potential during peak flows. Courthouse Wash drains 102 square miles, has an average discharge of 2.12 cfs, and produces peak flows reaching 12,300 cfs. Courthouse and Moab Washes are ephemeral and are dry much of the year. Courthouse Wash sustains flows for longer durations than Moab Wash, which drains an area of only 5 square miles (Smith Technology Corporation 1996). Moab Wash is an ungaged stream.

The Dolores River and the Green River empty into the Colorado River upstream and downstream, respectively, from Moab and the tailings pile. The Scott M. Matheson Wetlands Preserve (Matheson Wetlands Preserve), a shallow wetland open to the public and managed jointly by the Nature Conservancy and the Utah Division of Wildlife Resources (UDWR), is located across the river from the pile.